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Isometric exercise and pain in patellar tendinopathy: A randomized crossover trial.

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ABSTRACT

Objectives: The aim of this study was to compare the acute effects of isometric versus dynamic resistance exercise on pain during a pain-provoking activity, and exercise-induced hypoalgesia in participants with patellar tendinopathy.

Design: This study was a pre-registered randomised crossover study. Participants were blinded to the study hypothesis.

Methods: Participants (N=21) performed a single session of high load isometric resistance exercise or dynamic resistance exercise, in a randomised order separated by a 7-day washout period. Outcomes were assessed before, immediately after, and 45 min post-exercise. The primary outcome was pain intensity scored on a numeric pain rating scale (NRS; 0-10) during a pain-provoking single leg decline squat (SLDS). Secondary outcomes were pressure pain thresholds (PPTs) locally, distally and remotely, as well as tendon thickness.

Results: There was a significant decrease in pain NRS scores (mean reduction 0.9, NRS 95%CI 0.1 to 1.7; $p=0.028$), and increase in PPTs at the tibialis anterior muscle (mean increase 34 kPa 95%CI 9.5 to 58.5; $p=0.009$) immediately post-exercise. These were not sustained 45 min post-exercise for pain (NRS) or PPTs ($p>0.05$). There were no differences between exercise on any outcome.

Conclusions: While patients with patellar tendinopathy decreased pain during SLDS in response to resistance training, but the magnitude was small. Contraction mode may not be the most important factor in determining the magnitude of pain relieving effects. Similarly, there were only small increases in PPTs at the tibialis anterior which were not superior for isometric exercise.

Keywords: pain measurement, pain threshold, psychophysiology, exercise induced hypoalgesia, resistance exercise, pain relief, tendon, athletes

Practical implications

- Isometric exercises for patellar tendinopathy were advised to be implemented for acute pain relief despite lack of evidence supporting their efficacy
- In the current study, small and varying decreases in pain were observed following isometric and dynamic exercises, which was not sustained for 45 minutes
- When discussing acute pain management options, patients should not be told to expect complete pain reduction from resistance exercises
- Due to the lack of superiority of the acute effect of either isometric or dynamic exercise, patient preferences can be used to guide exercise selection for acute pain management.

INTRODUCTION

Patellar tendinopathy is one of the most common musculoskeletal pain problems associated with sport, particularly those that includes jumping activities¹. One of the most commonly used strategies for managing patellar tendinopathy are loading programs i.e. resistance training. Resistance training (i.e. a training programme) is effective in reducing pain for a range of musculoskeletal pain conditions, including tendon pain (tendinopathies)^{2,3}. For long-term rehabilitation of tendinopathies, high load resistance training is frequently used from several weeks to months², with level one evidence supporting its effect compared to other treatments such as stretching for long-term management³. Eccentric and high load dynamic exercises are often used during rehabilitation, although the choice of optimal modality for improving patient outcomes is heavily debated^{4,5}. There are multiple proposed mechanisms behind the positive effects exercise rehabilitation including local effects on the tendon structure⁴, the muscle⁶ and central effects⁷.

In addition to resistance training, an acute bout of exercise can also acutely reduce pain sensitivity (hypoalgesia) and pain intensity to normally painful stimuli (analgesia). This is also termed exercise-induced hypoalgesia (EIH) in healthy individuals and is a short time-limited effect as a result of neurophysiological mechanisms involved in processing noxious stimuli⁸. This acute effect is likely independent of structural adaptations, and depend on neurophysiological modulation, such as opioid analgesic systems⁹⁻¹¹, or potentially due to the observed decreases in tendon thickness following exercise¹².

It therefore cannot be assumed that the exercise paradigms which work cumulatively over time are the best for acute pain reduction. The effect of exercise on pain and hypoalgesia has typically been evaluated using short-term aerobic exercise, or isometric resistance exercise, and investigated as the effects on pain sensitivity, measured by changes in pain thresholds^{8,13,14}. However, the optimal mode and dosages for reducing pain is unknown.

Rio and colleagues¹⁵ found that a single bout of isometric exercise induced greater immediate subjective pain relief during the single leg decline squat, an aggravating task for patellar tendinopathy (with an effect size of 1.1 compared to dynamic exercise), indicating the potential for isometric exercise as an acute pain management tool. However, contradictory results have been found, with another study

28 finding a much lower pain relieving effect of isometric contractions ¹⁶, and attempts to replicate the
29 analgesic effect in other tendinopathies have been unsuccessful ¹⁷. Despite this, isometric exercise is
30 advocated as providing a greater pain inhibition compared to dynamic exercises for tendinopathies, and
31 specifically patellar tendinopathy ¹⁸. Consequently, there is currently conflicting evidence for the
32 acute effect of isometric exercises in patients with patellar tendinopathy. A larger and
33 adequately designed study is needed to improve knowledge within this field.

34 As most research to date has focused on the long-term effects of maintained resistance training in
35 this population (and associated structural adaptations), there is a lack of research on the short-term effects
36 including exercise induced hypoalgesia which can be quantified using quantitative sensory testing (QST),
37 and on the change in hypoalgesia response over time.

38 The primary aim of this study was to compare the acute effects of isometric versus dynamic
39 exercise during a pain-provoking activity, in participants with patellar tendinopathy. The primary
40 hypothesis is that isometric exercise will induce greater pain reduction during a pain aggravating activity
41 in comparison to dynamic exercises. The secondary objective was to compare the effect of isometric and
42 dynamic exercise on pressure pain sensitivity locally at the patellar tendon, as well as distally and on a
43 remote site. A tertiary aim was to evaluate changes of patellar tendon thickness following the exercises.

44

45 **METHODS**

46 This study was designed as a randomised crossover superiority trial, where participants were blinded to
47 the study hypothesis. The protocol was approved by the local ethics committee (N-20160084), and all
48 participants provided written informed consent prior to participation. The trial was pre-registered on
49 clinicaltrials.gov before inclusion of the first participant (NCT03528746). The reporting of this study
50 follows the CONSORT guidelines, the Pain-specific CONSORT supplement checklist and TIDieR
51 guidelines for intervention reporting. All procedures were pilot tested in participants who were healthy
52 (N=8) and with patellar tendinopathy (N=2) prior to inclusion of the first participant.

53 Based on the pilot study, it was decided not to include pain during exercise due to the cognitive process of
54 evaluating pain which may influence subsequent pain recording and impede replication of the previous

55 trial. As a result, pain during exercise was not collected as a secondary outcome, which was a protocol
56 deviation.

57

58 Participants with patellar tendinopathy were recruited through Aalborg University and University College
59 of North Denmark, local sports clubs, local clinics and social media. Interested participants who had
60 patellar tendon related pain were invited for a clinical examination to establish the diagnosis, rule out
61 other common causes of anterior knee pain (e.g. Patellofemoral Pain) and assess eligibility for inclusion
62 into the study. The inclusion and exclusion criteria were as follows: (1) Participants were required to have
63 patellar tendinopathy and be aged 18-40 years. (2) Diagnosis of patellar tendinopathy was made by a
64 physiotherapist supervised by an experienced rheumatologist (JLO), which was based on the criteria in
65 Rio et al.¹⁵ as follows; pain localised to the inferior pole of the patella at palpation and during jumping
66 and landing activities, and pain during testing on the single-leg decline squat (SLDS). The patellar
67 tendinopathy diagnosis was confirmed by the presence of characteristic features on ultrasound imaging
68 (i.e., hypoechoic area, Doppler and focal enlarged tendon were considered characteristic features, but not
69 all had to present in each patient). Ultrasound (BK Flex Focus 500, BK Medical, Denmark) was done
70 with the knee flexed to approximately 60 degrees with a transducer head of 48X13mm (High Frequency
71 Linear 18L5, BK Medical, Denmark). Finally, participants were required to have a minimum pain (worst
72 pain in the last week) of 3 / 10 on an 11-point numeric rating scale (NRS). Participants were excluded if
73 they had any concurrent knee pathologies (e.g. the presence of a diffuse knee pain presentation indicative
74 of PFP with or without tendinopathy), or previous knee surgery or had received a corticosteroid injection
75 within the previous six months.

76

77 Participants attended two sessions, one week apart, at approximately the same time of day. On the first
78 day, the diagnosis and eligibility was determined, in line with criteria outlined above. If participants were
79 eligible, demographic data, including sex, age, height, weight, and sports participation (type and hours per
80 week) were recorded, whether participants had unilateral or bilateral pain, and if bilateral, which was the
81 most painful limb. In addition, participants completed the Victorian Institute of Sport Assessment-Patella

82 (VISA-P questionnaire) , duration of pain condition, as well as average and worst pain intensity in the
83 past week (measured on an 11-point NRS, ranging from 0 to 10 from no pain to worst possible pain).

84 After the baseline assessment, participants performed either isometric or dynamic exercise,
85 according to the randomisation sequence (see below). The second exercise of the allocation sequence was
86 completed one week later, at the same time of day (within two hours of the initial assessment).

87 The sequence exercise type was randomised by an independent researcher (not involved in any
88 other aspects of the study) using a computer generated allocation sequence on random.org. The generated
89 sequences were then sealed in opaque envelopes. The researcher instructing and supervising the exercise
90 protocols was blinded to sequence allocation, until after subjects were enrolled and completed baseline
91 testing, at which point the participant randomly selected an envelope which determined their allocation.
92 Outcome parameters were recorded immediately pre-exercise, immediately post exercise and 45 min post
93 exercise.

94

95 Both the isometric and dynamic exercise protocols were based off previously published protocol by Rio
96 and colleagues ¹⁵.

97 The isometric exercise session was conducted at 70% maximal voluntary isometric contraction (MVIC).
98 Prior to completing the isometric exercise, the MVIC was assessed using isokinetic dynamometry
99 (Biodex System 4 Pro) ¹⁵. Participants were seated in a stable position in the dynamometer, fixated with
100 trunk and lower limb straps with the knee at 60° of knee flexion. Participants were familiarised with the
101 procedure and issued standardised instructions to perform a maximal effort knee extension against the
102 dynamometer for 30 seconds. After a short break, the test was repeated three times. The peak torque
103 recorded during these three efforts was the MVIC.

104 For the isometric exercise session, participants completed static isometric quadriceps contractions in
105 the Biodex. Participants were required to isometrically exert a force equivalent to 70% of the MVIC, and
106 to sustain this for 45s while seated with their knee in 60° flexion. The torque was verified by the Biodex
107 system. One 45s repetition constituted a set, and this was repeated five times with two minutes break in-

108 between. Participants received standardised and neutral vocal encouragement and feedback. “Push more,
109 Push less, Great, Come-on”.

110

111 The dynamic exercise was leg extension, completed in a leg extension machine (Body Solid Inc,
112 GLCE365). First, the maximum load that can be lifted for eight repetitions (8RM) at 6 sec per repetition
113 through 90 degrees range of motion (ROM) was determined. This was assessed according to the National
114 Strength and Conditioning Association (NSCA) guidelines for RM testing. The 8RM load was used for
115 the dynamic leg extension exercise with a pace (guided by a metronome) of three seconds per concentric
116 contraction, 0s isometric and three seconds eccentric contraction through 90 degrees ROM. This was
117 repeated for three sets of eight repetitions, with two minutes break between each set. Similar to the
118 isometric exercise, participants received standardised neutral vocal encouragement.

119

120 The primary outcome was pain intensity assessed during a single leg decline squat (SLDS), a reliable test
121 for provoking pain in patients with patellar tendinopathy ^{15, 19}. Participants were asked to stand on one
122 limb, on a decline board, so they were in approximately 25 degrees of plantar flexion of the ankle joint.
123 They were then asked to perform a squat, to 60 degrees of knee flexion. This was repeated three times.
124 Participants provided a NRS score, anchored at left with ‘0, no pain’ and at right with ‘10, worst possible
125 pain’. If participants had bilateral patellar tendinopathy, data from the ‘most painful’ limb (indicated by
126 participants) was used. The average NRS score across the three SLDS was used for further analysis.

127

128 The pressure pain thresholds (PPTs) were recorded using a hand-held algometer (Somedic, Hörby,
129 Sweden) with a 1-cm² probe (covered by a disposable latex sheath). The tester placed the probe
130 perpendicular to the skin at the test site, and increased the pressure 30 kPa/s. Participants were equipped
131 with a hand-held button, which they were instructed to press at the first instance the sensation changed
132 from pressure, to pain. The pressure at this point defined the PPT. PPTs were assessed locally at the most
133 painful site point on the tendon, with the knee flexed to 90° as per previous methods in patellar
134 tendinopathy, which have demonstrated excellent reliability ²⁰. PPTs were further assessed bilaterally at

the patellar tendon. For participants with unilateral pain, the PPT on the contralateral limb was taken directly distal of the patellar apex, as previously used in asymptomatic individuals²⁰. In addition to this, PPTs were assessed at the tibialis anterior muscle at the muscle belly on the test leg and on the contralateral extensor carpi radialis brevis muscle belly. PPTs were recorded in triplicates and the average value were used for further analysis. At each session, the location of PPTs was marked on the participant during the baseline assessment to ensure reproducibility in the post-exercise assessments.

Ultrasound (BK Flex Focus 500, BK Medical, Denmark), was used to quantify patellar tendon thickness. The ultrasound measurements were carried out with the participants in a supine position with the knee flexed to approximately 60 degrees with a transducer head of 48X13mm (High Frequency Linear 18L5, BK Medical, Denmark). To determine thickness, a transversal scan taken 1cm from the apex of the patella (marked by marker to ensure it was repeated at the same point post-exercise). The thickest portion of the tendon was used for measurement by manually selecting two points and measuring the vertical distance directly in the ultrasound software. The average of three measurements was used for analysis.

The sample size was based on the results from Rio et al. where they found a mean reduction of 6 NRS points in response to isometric exercise¹⁵ in volleyball players. We aimed to account for a potentially smaller effect size due to a more heterogeneous group (wider sports participation and including females). Therefore, our samples size was based on detecting a 2±3 point difference between exercises ($p < 0.05$) in NRS with a within groups design and a power of 0.9 which would require 21 participants.

Statistical analysis

Statistics were undertaken according to a pre-established statistical analysis plan (protocol). All outcomes were approximately normally distributed, determined by visual inspection of Q-Q plots. Data are reported as mean and 95% confidence interval unless otherwise stated. Significance was accepted at $P < 0.05$.

To determine if there was an effect of exercise order on the primary outcome, an independent samples t-test was run (independent grouping variable of allocation sequence; isometric *versus* dynamic)

was used to examine the within subject mean differences for each assessment of the primary outcome (pain during the single leg squat) ²¹. Similarly, to check the assumption of negligible carryover effects, an independent t test was calculated on the within subjects sum of effects for the primary outcomes (pain during SLDS) from both periods²¹.

Separate two-way repeated measures (two within subject factors) analysis of variations (ANOVAs) were undertaken for the dependent variables of interest (primary and secondary outcomes). The within subject's factors were exercise type (isometric *versus* dynamic), and time (pre- *versus* post exercise *versus* 45 min post- exercise). In addition to this, for both isometric and dynamic interventions, effect sizes was be calculated and plotted for the change in NRS scores of the SLDS evoked pain. In cases where the assumption of sphericity was violated according to the results of Mauchly's sphericity test, Greenhouse-Geisser adjustment was used.

The primary outcome was also analysed as a categorical variable, defined as the number of responders to each intervention, quantified by the number of participants with a change equal to, or above the minimally clinically important difference (MCID) in NRS i.e. 2 points change ²². McNemars test was used to test for differences in the proportion of participants categorised as responders to each of the interventions.

RESULTS

Participants were recruited and assessed for eligibility between July 2018 and September 2018 (Figure 1). Recruitment was ceased when 21 eligible participants were enrolled as per the a priori protocol and sample size calculation. Of these 21, one participant loss to follow-up (due to family reasons), and did not complete the dynamic exercise intervention (Figure 1). Therefore, twenty participants were included in the analysis (Figure 1). The severity of the participant's tendon pain was expressed with the VISA-P score (mean score: 47.8/100, Table 1) and the majority had contacted at least one health care practitioner (12 contacts to general practitioner, 12 to physiotherapist, one to and orthopaedic surgeon and one to a rheumatologist). All participants were actively engaged in at least one sport/activity (Table 1), with a

189 large proportion conducting strength training (including Cross-Fit) (n=12 other sports), and other sports
190 included handball (n=3), gymnastics (n=3) volleyball (n=1), athletics (n=1), triathlon (n=1) and running
191 (n=1).

192 There were no significant differences on the primary outcome between the two sequence groups
193 (isometric-dynamic and dynamic-isometric) for the mean differences, or the sum of effects, indicating no
194 influence of exercise order and negligible carryover effects respectively.

195

196 In the ANOVA there was no significant interaction between mode of exercise and time on NRS scores of
197 pain during SLDS ($F(2,38)=0.6$, $p=0.561$, partial $\eta^2 = 0.03$; Figure 2; Table 2). There was a main effect of
198 time ($F(1.4,38)= 4.7$, $p=0.028$), partial $\eta^2 = 0.19$). The pain NRS score was lower immediately post
199 exercise (mean difference 0.9 NRS points 95%CI 0.1 to 1.7; Post-hoc: $p=0.028$) compared to baseline.

200 There were no significant differences in NRS scores of pain during SLDS between 45 min post exercise
201 and baseline (mean difference 0.4 NRS points 95%CI -0.1 to 0.8; Post-hoc: $p= 0.089$). The proportion of
202 responders (NRS scores during SLDS reduced by 2 points compared with baseline) were not significantly
203 different between isometric and dynamic exercise interventions immediately after the exercise (4 versus 6
204 respectively; $p = 0.73$) or 45 min after the exercise (0 versus 4 respectively; $p=0.16$).

205

206 For PPTs at the patellar tendon of the painful knee, there was no significant interaction between **mode of**
207 **exercise** and time ($F(1.6,38)=0.0$, $p=0.196$, partial $\eta^2 = 0.08$) or main effect of time ($F(2,38)=1.5$,
208 $p=0.239$, partial $\eta^2 = 0.07$) (Table 3).

209 There was no significant interaction effect between mode of exercise and time for PPTs at the
210 tibialis anterior muscle ($F(2,38) =0.5$, $p=0.62$, partial $\eta^2 = 0.03$) (Table 3) but there was a main effect of
211 time ($F(2,38)=4.0$, $p=0.027$, partial $\eta^2 = 0.17$). Pairwise comparisons revealed increased PPTs at the
212 tibialis anterior muscle post exercise compared to baseline (mean difference 34 kPa 95%CI 9.5 to 58.5,
213 $p=0.009$), with no differences 45 min post exercise compared with baseline (mean difference 17.2 kPa
214 95%CI -12.3 to 46.7, $p=0.238$) (Figure 3).

There was no significant interaction between mode of exercise and time ($F(2,38)=0.7, p=0.519$, partial $\eta^2 = 0.03$) (Table 3) or main effect for time ($F(2,38)=1.1, p=0.340$, partial $\eta^2 = 0.06$) for PPT at the contralateral extensor carpi radialis brevis muscle.

For PPTs at the contralateral patellar tendon, there was no significant interaction between mode of exercise and time ($F(1.5,28.8)=0.04, p=0.603$, partial $\eta^2 = 0.02$) (Table 3) or main effect for time ($F(1.4,26.8)=0.9, p=0.383$, partial $\eta^2 = 0.05$).

There was no significant change in patellar tendon thickness from pre to post exercises ($F(2,38)=0.5, p=0.593$, partial $\eta^2=0.03$) (Table 3) or interaction between mode of exercise and time ($F(2,38)=0.2, p=0.821$, partial $\eta^2=0.01$).

DISCUSSION

The current study aimed to test previous findings on the short-term analgesic effect of isometric resistance exercise for patients with patellar tendinopathy. Contrary to our pre-defined hypothesis, no significant difference was found between isometric and dynamic resistance exercise on acute pain during a pain-provoking activity, or pain sensitivity. There was an effect of time, i.e. a small decrease in self-reported pain during movement evoked pain immediately following exercises, with no differences between isometric or dynamic exercises. This finding was supported by the increased PPTs at the tibialis anterior muscle immediately post exercise, indicating EIH, but not at the patellar tendon or in other locations indicating a lack of a systemic effect. However, no significant difference was observed between the two exercises for either outcome. Changes were not sustained 45 minutes post-exercise, despite a tendency for pain to be lower than at baseline ($p=0.089$), indicating pain ratings were returning to baseline at the 45min follow-up. Only a small number of participants reported a clinically relevant decrease in pain, which was not different between the exercise conditions.

Overall, the magnitude of the exercise-induced changes in pain intensity found in the current study were discouraging, based on the previous data indicating a substantial effect of isometric exercise (over 6

points on the NRS)¹⁵. The current study contradicts the magnitude of these effects and challenges the generalisability of previous findings. Despite replicating the exercise protocol, the magnitude of pain reduction to dynamic exercise reported by Rio and colleagues¹⁵ was also much larger and clinically relevant, compared to the present results where only a small proportion of participants had a clinically relevant change in pain after exercise. The populations are similar in terms of severity (VISA-P score of 47.9 in the current study compared to 52.8¹⁵, although the relatively long symptom duration and high proportion of bilateral cases in the current study could indicate a high severity. However, these data were not provided by Rio and colleagues which hampers a direct comparison in populations. Furthermore, the study by Rio and colleagues included only n=6 adult male volleyball players, which would make the generalisability to wider populations of patellar tendinopathy limited. We included all types/sports and both males and females, and sex may be important due to established sex differences in pain perception, although women have been demonstrated to be more responsive to EIH²³. On the other hand Pearson et al.¹⁶ recently compared short versus longer contraction times in patients with patellar tendinopathy and found they were equally effective on acute pain relief with pain during a SLDS reduced by 1.7 cm on a VAS scale. The magnitude of change in pain is much more similar to our results compared to the study by Rio and colleagues, which may indicate the large decrease in pain following contractions in these 6 individuals may not be generalizable. Several papers which have investigated the acute pain-relieving effects of isometric exercises on common lower limb tendinopathies. In Achilles tendinopathy,¹⁷ some patients reported an improvement, while others had a pain flare-up after the heavy isometric loading while Riel et al.²⁴ did not find a difference in the acute effects on pain between the two exercise types, in patients with plantar fasciopathy.

In our study, EIH was detected distally at the tibialis anterior by increases in PPTs immediately post exercise. The observed magnitude of the EIH response detected by PPTs distally after exercise is similar to that which has previously been detected after isometric or aerobic exercise^{23,25}. Despite this, a positive EIH response was not found locally at the patellar tendon or remotely at the extensor carpi radialis brevis muscle. This is surprising, as EIH is considered a systemic/centrally mediated pain modulation^{11,26}. This could be due to dysfunctional endogenous pain inhibition, as has been demonstrated in patients with other

269 musculoskeletal pain conditions such as shoulder myalgia ²⁷. It cannot be ruled out that such
270 manifestations are present in painful- persistent tendinopathies, considering the mean pain duration of the
271 current sample is 24 months, and patients with patellar tendinopathy have previously been demonstrated
272 increased pain sensitivity ²⁸. However, this is speculative as we did not include a control group without
273 tendon pain for comparison.

274

275 While the mechanisms of exercise on pain and EIH are not yet fully understood, there appear to be
276 multiple analgesic systems which play a role ^{9, 10}. Some characteristics, such as exercise stress/severity
277 (e.g. exercise duration and temperature) appear to influence the relative contribution of opioid versus non-
278 opioid mechanisms in animals ²⁹. Further research is needed to investigate which other parameters
279 contribute to this, and whether results are similar between patient populations and healthy controls. For
280 example, data in healthy subjects show that both short and long duration contractions, and low and high
281 load isometric exercise affect pain perception with hypoalgesia occurring after only one minute of low
282 load (25%MVIC) contractions ^{8, 13, 14}. Whether or not these parameters have similar responses on tendon
283 pain has yet to be determined. One possibility, was that changes in patellar thickness may explain the
284 potential effect of one exercise over another. However, in the current study we found no changes in
285 tendon thickness following resistance training exercises, which is in contrast to previous research
286 showing that acute tendon overload via cross-fit training resulted in an increased tendon thickness in
287 healthy individuals¹² which could indicate that the volume or intensity play a role. However, further
288 research in patients with patellar tendinopathy is needed to determine if such an acute change in thickness
289 is indeed associated with changes in symptoms.

290 In healthy individuals meta-analysis indicated that both isometric and dynamic exercise are
291 effective in influencing pain perception ⁸. Isometric exercise has commonly been used, many studies have
292 also evaluated aerobic exercise ⁸, and there are data available regarding dynamic or concentric resistance
293 exercise. These have found dynamic exercise effective ^{8, 30}, and data from first investigations over 20
294 years ago, show large effect sizes of around 0.99-1.08 ³¹.

295

296 Isometric exercises for immediate pain relief was quickly highlighted as a strong tool for managing pain
297 in patients with lower limb tendinopathies ^{7, 18}. Based on the current study there was no statistically
298 significant superior effect of isometric exercise compared to dynamic exercises. It should be noted that
299 this study included adult participants with chronic tendinopathy of a relatively long symptom duration. It
300 is unclear if participants' with acute tendinopathy or adolescents with other patellar tendon related pain
301 conditions (e.g. Osgood Schlatter) may produce different results. Further research is needed to further
302 elucidate the mechanisms underpinning acute and cumulative exercise induced analgesia in order to
303 inform how to modulate exercise intensity and dosages to optimise outcomes for patients with
304 tendinopathy in both the short and long term.

305 One of the strengths of the current study is the study design, which was pre-registered with the statistical
306 analysis plan specified a priori in the protocol. Additionally, we based our diagnosis of patellar
307 tendinopathy on objective characteristic features examined by ultrasound, in addition to the clinical
308 assessment. One of the limitations of the current design is the lack of a 'no-exercise' control condition, so
309 it cannot be ruled out the SLDS NRS declines over time. However, this limitation doesn't affect the
310 overall conclusion regarding the superiority of the contraction modes. Another limitation is that the
311 assessor was not blinded to the different exercise conditions. Further, isometric and dynamic strength was
312 measured on the same day as testing. However, as the EIH effect is relatively short-lived and participants
313 were given a break prior to baseline pre-exercise assessment, and as this was the same under both
314 conditions, we do not believe this affects the conclusion of results. The effect of the different exercises on
315 the affective dimension of pain (i.e. pain unpleasantness) was not documented, which is also a limitation.
316 Finally, we did not detect a functional EIH response at all sites, but without a control group cannot
317 determine if these patients with patellar tendinopathy have a decreased response to exercise induced
318 analgesia compare to healthy individuals without musculoskeletal pain. Further research could investigate
319 this, as well as whether or not it has implications for treatment outcomes. Similarly, due to the large
320 heterogeneity in the acute effects to acute pain relief, whether or not this is associated with sustained pain
321 relief following a resistance training intervention is warranted.

323 The current study demonstrates that there is no statistically superior immediate effect of isometric
324 exercise compared to dynamic exercise on pain, or on pain perception (hypoalgesia). The optimal mode
325 and dosage for inhibiting pain in patients with patellar tendinopathy has been controversial, but this study
326 indicates that the contraction mode may not be the most important factor.

327

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403 **Figure Legends**

404 **Figure 1.** Flowchart of included participants.

405 **Figure 2.** Individual participant data plot of pain during SLDS on the test limb before, immediately after
406 and 45 min after isometric exercise (top) and dynamic exercise (bottom).

407 **Figure 3.** Mean change (95% CI) in pressure pain thresholds from baseline. (*indicated significant
408 difference from baseline; test indicates test limb; contra indicates contra-lateral limb).

409

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Enrollment

Assessed for eligibility (n= 27)

Excluded (n= 6)

♦ Not meeting inclusion criteria (n= 6)

Randomized (n= 21)

Allocation

Allocated to isometric exercise first (n= 10)

♦ Received allocated intervention (n=10)

Allocated to dynamic exercise first (n= 11)

♦ Received allocated intervention (n=11)

Follow-Up

Lost to follow-up (family commitments) (n= 1)

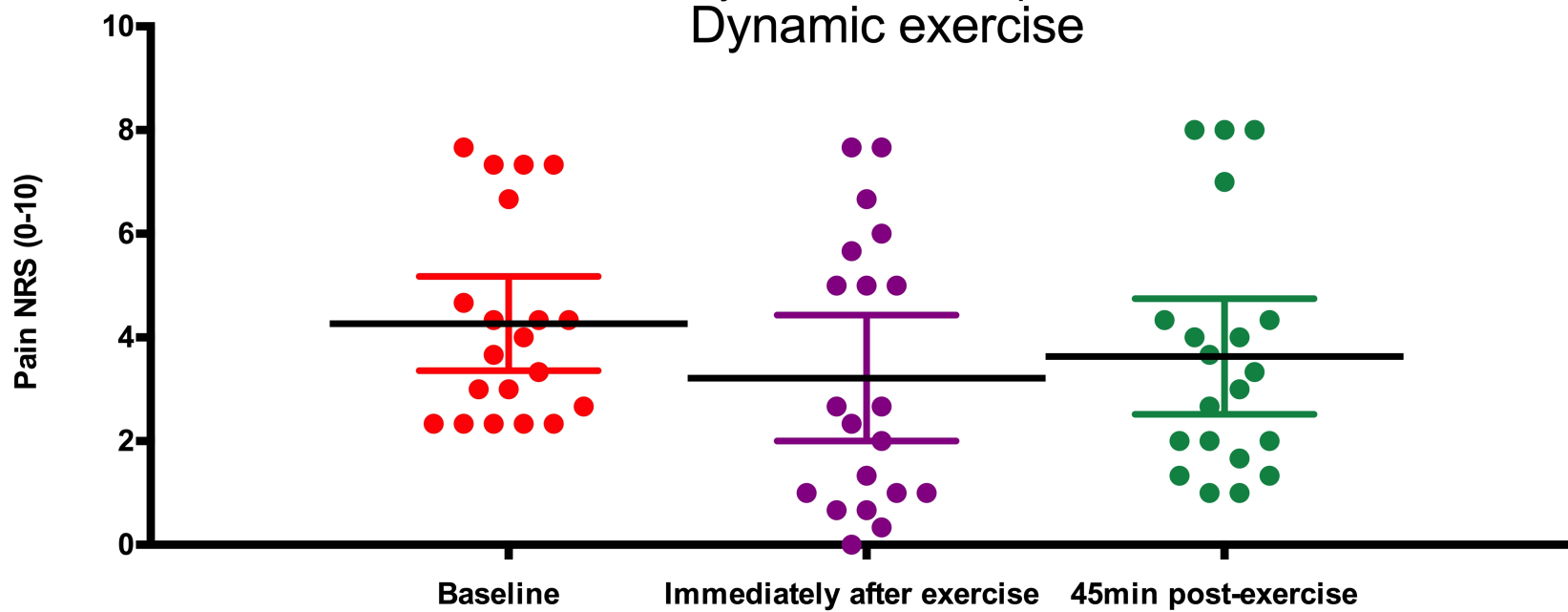
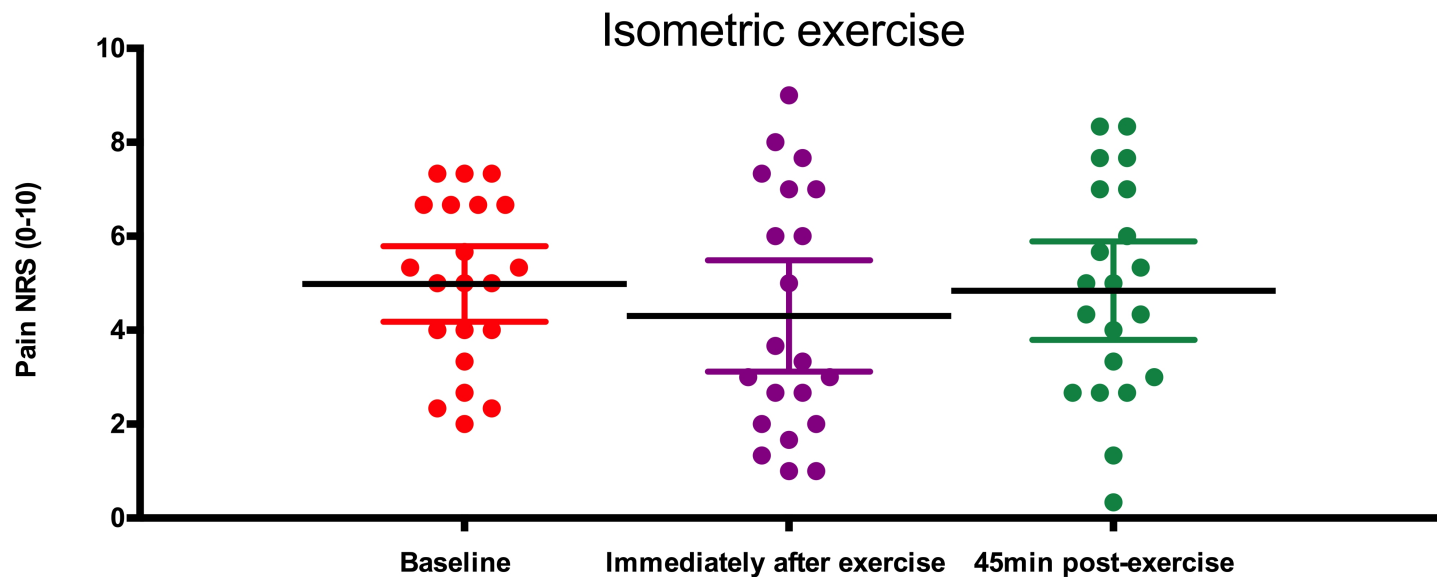
Lost to follow-up (n= 0)

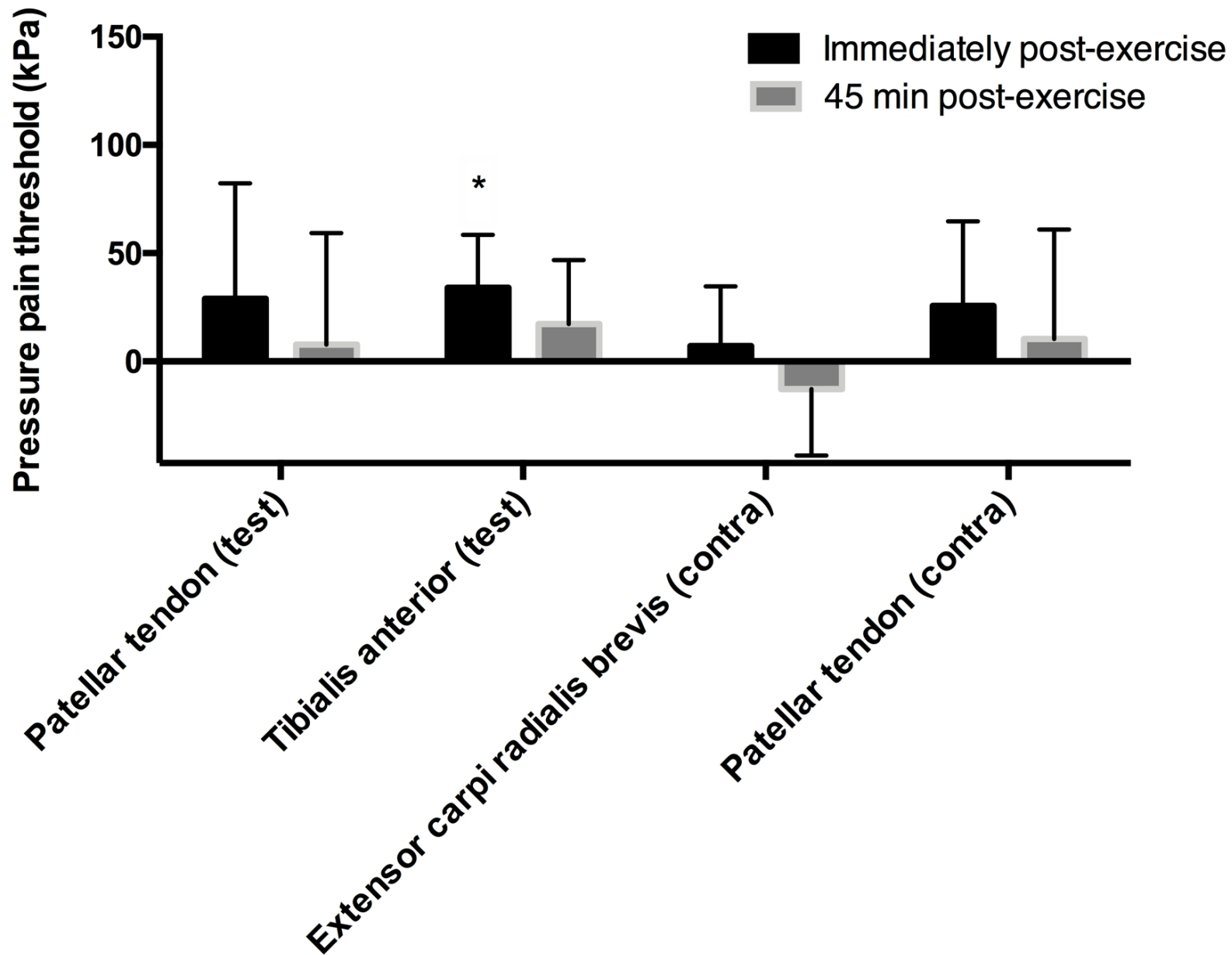
Analysis

Analysed (n= 9)

♦ Excluded from analysis (did not complete dynamic exercise intervention due to loss to follow-up) (n=1)

Analysed (n= 11)





Age (years)	26.5 (6.4)
Sex (% female)	41
BMI* (kg/m²)	25.6 (23.2 – 29.1)
VISA-P Score (0-100, 100 being best)	47.9 (11.6)
Symptom duration* (months)	24 (10 -84)
Bilateral pain (%)	52
Contact with health care practitioner due to knee pain (% Yes)	82
Worst pain past week (NRS points)	7.9 (1.6)
Mean pain past week (NRS points)	4.3 (1.6)
Weekly sports participation (h)	8.8 (4.2)

Table 1. Participant demographics and characteristics at baseline reported as mean (standard deviation) unless otherwise indicated (*: indicates median and inter-quartile range). VISA-P: Victorian Institute of Sport Assessment-Patella.

Time	Mean	95% CI
	Isometric	
<i>Baseline</i>	5	4.1 to 5.8
<i>Immediately post- exercise</i>	4.2	3.0 to 5.5
<i>45 min post-exercise</i>	4.8	3.7 to 5.9
	Isotonic	
<i>Baseline</i>	4.3	3.4 to 5.2
<i>Immediately post- exercise</i>	3.2	2.0 to 4.4
<i>45 min post-exercise</i>	3.6	2.5 to 4.7
	Difference (isometric - isotonic)	
<i>Change from baseline to immediately post- exercise</i>	-0.3	-1.3 to 0.7

Time		Isometric		Dynamic		Mean difference Isometric vs Dynamic	
		Mean	95% CI	Mean	95% CI	Change from baseline to post- exercise	95% CI
PPT Patellar tendon (kPa)	<i>Baseline</i>	489	399 to 579	454	348 to 560		
	<i>post- exercise</i>	492	371 to 613	509	383 to 634	-53	-128 to 23
	<i>45 min post- exercise</i>	458	363 to 552	470	356 to 583		
PPT Tibialis Anterior (kPa)	<i>Baseline</i>	442	349 to 536	407	321 to 493		
	<i>post- exercise</i>	485	377 to 593	432	343 to 522	18	-38 to 73
	<i>45 min post- exercise</i>	456	349 to 546	427	337 to 518		
PPT contra- lateral extensor carpi radialis brevis (kPa)	<i>Baseline</i>	271	225 to 318	287	225 to 350		
	<i>post- exercise</i>	293	225 to 361	280	210 to 350	29	-14 to 72
	<i>45 min post- exercise</i>	263	15 to 332	270	214 to 326		
PPT contralate ral patellar tendon (kPa)	<i>Baseline</i>	553	435 to 670	526	413 to 640		
	<i>post- exercise</i>	590	465 to 715	540	421 to 660	23	-63 to 110
	<i>45 min post- exercise</i>	559	432 to 687	541	417 to 664		
Patellar tendon	<i>Baseline</i>	0.5	0.45 to 0.55	0.51	0.47 to 0.55		

thickness (cm)	<i>post-exercise</i>	0.49	0.44 to 0.53	0.5	0.46 to 0.55	0.01	-0.04 to 0.03
	<i>45 min post-exercise</i>	0.5	0.45 to 0.55	0.51	0.46 to 0.55		

Table 2. Mean (95% CI) pressure pain threshold (PPT) and patellar tendon thickness at baseline, immediately post-exercise and 45min post-exercise.